

## Introduction to Plate Tectonic Theory, Geodesy, and VLBI

The plate tectonic theory is a relatively new, accepted only around 50 years ago. The following website contains a more detailed and lesson plans on plate tectonics, geodesy, and VLBI.

<http://www.haystack.mit.edu/edu/pcr/GPS/index.html>

### The Plate Tectonic Theory

In 1912, Alfred Wegener proposed that all the continents were at one time a single large continent that broke apart, and drifted through the ocean floor to where they are now. Wegener was first influenced by how the continents fit together, especially western Africa and eastern South America. When he compared the rock structures and composition of the coastlines of the continents mentioned above, he found them to be very similar. Wegener also examined fossil distribution, location and similarity and again found a strong correlation. For example, why was a specific trilobite only found in Massachusetts and in Scotland?

His theory of continental drift was not accepted in the scientific community because it conflicted with the established theories which were:

1. The continents' position are basically unchanged since when were formed. (Permanentists)
2. The Earth gradually contracted and the ocean floor became dry land, and dry land, in turn, became ocean floor (Contractionists)

South African geologist, Alexander Du Toit spent five months in Brazil, Uruguay and Argentina examining the geology. He found that the same plant and animal fossils he knew in South Africa were embedded in the rock in the same sequence layer by layer.

Paleomagnetism, the study of the magnetism in rocks, provided more substantiation. When molten igneous rocks solidify, magnetic minerals in the rocks, (for example, iron oxides) align themselves with the Earth's magnetic field. The deviations in the magnetic alignment in these rocks from the current direction of the Earth's magnetic field showed that the continents have moved.

Finally during the 1960's two Cambridge scientists, Drummond Matthews and Fred Vine, discovered that on either side of the Mid-Atlantic Ridge there were a series

of linear magnetic anomalies. Strips of ocean crust had alternating magnetic orientations. These observations showed that the sea floor was spreading and new oceanic crust was continually forming along mid-ocean ridges as the two halves of an ocean move apart. Changes in magnetic orientations could have only occurred as the Earth's magnetic field changed over long periods of time.

From the above scientific evidence showed that the plate tectonics theory was correct and now it is universally accepted.

The surface of the Earth consists of a series of thin rigid, plates which are in constant motion. The surface of each plate is composed of oceanic crust or continental crust. The lower part consists of the rigid upper layer of the Earth's mantle. The rigid plates pass gradually downwards into the plastic layer of the mantle. The plates may be up to 70 km thick if composed of oceanic crust or 150 km if incorporating continental crust. Plates move at different velocities

The Earth's tectonic, seismic, and volcanic activity occurs at the boundaries of neighboring plates. The current theory is that the plates are moved around by convection currents caused by the cooling of the core and radioactivity of the molten magma below the plates. The San Andreas Fault is the best known example. Two plates move slide laterally past each other, and no oceanic crust is created or destroyed.

The plate tectonic theory states:

1. Continents move across the surface of the globe
2. Earthquakes and volcanoes occur where the plate boundaries collide. Likewise minerals are most likely found in those regions.
3. New oceans may grow and different sedimentary basins evolve
4. Oceans and sedimentary basins are deformed and pushed up to produce mountains. Fossils of sea creatures can be found on the highest mountains.

## **Geodesy**

(From the Haystack website: <http://www.haystack.mit.edu/geo/index.html>)

Geodesy and geophysics are concerned mostly with what is going on under our feet, so it may seem ironic that these two disciplines are advanced by looking up at the stars! **VLBI** (**V**ery **L**ong **B**aseline **I**nterferometry) techniques, which were originally developed for studying radio objects in the universe, can, in effect, be turned upside down to do very precise studies of the Earth.

By simultaneously collecting data from a single radio source via a worldwide array of radio telescopes, the relative time-of-arrival of signals from that source to each telescope can be determined to within a few picoseconds (3 picoseconds = 1 mm of light travel time). By observing many radio sources spread widely over the sky over a period of 24 hours, data are collected that allow the ultra-precise measurements of the Earth and its orientation in space. The geodetic VLBI techniques in use at Haystack originated more than three decades ago at the Observatory, which continues to lead the way in new developments and improved accuracy in these important research methods.

### **Measuring Tectonic Plate Motion**

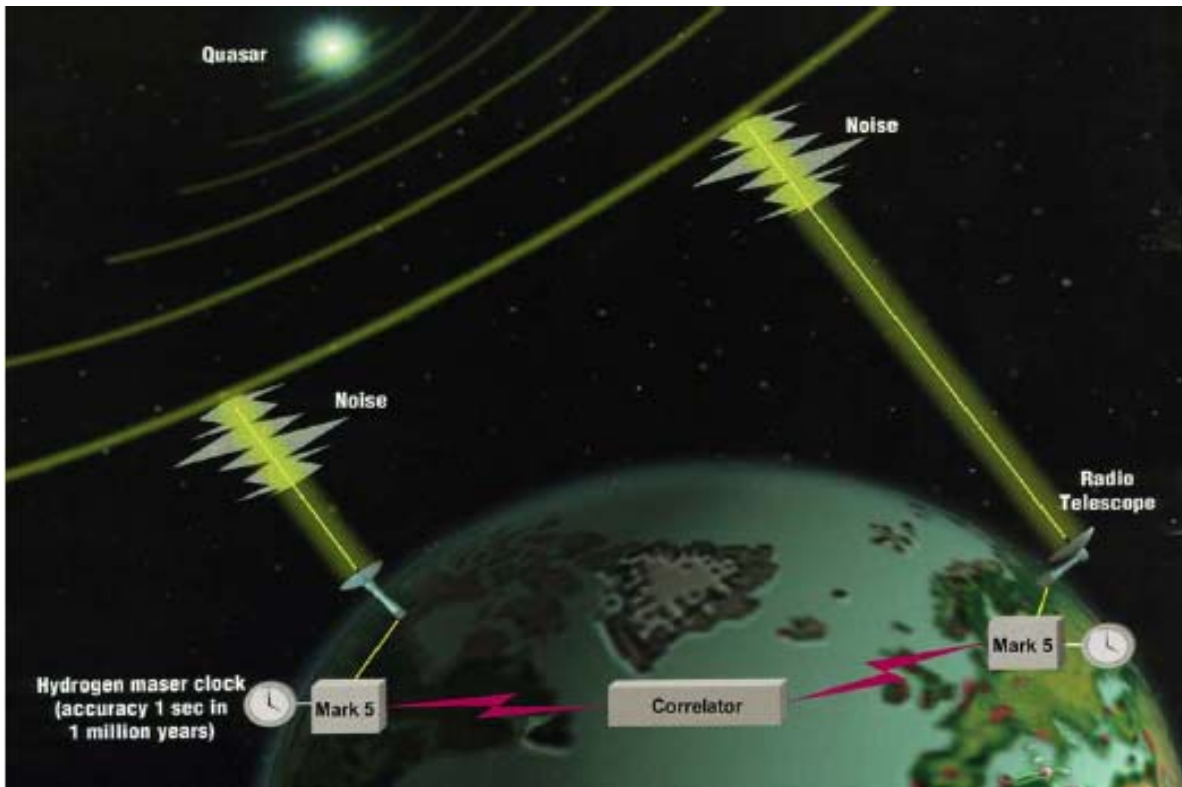
By determining the relative 3-dimensional position of globally distributed telescopes to a precision of a few millimeters (This is about 1 part in a billion!), motions of the Earth's tectonic plates can be directly measured. A 20-year time history of the distance between the Westford, Massachusetts antenna and an antenna in Germany shows that the separation of North America and Europe is proceeding at a steady rate of about 17 millimeters per year. Global tectonic motions measured by VLBI also allow scientists to measure changes in the position of the famous San Andreas Fault in California, where the Pacific plate slips past the North American plate at the rate of about 5 centimeters per year.

## Very Long Baseline Interferometry (VLBI) and How It Works



VLBI is a technique, used in radio astronomy, to improve data collection and analysis. An array of up to approximately 20 radio telescopes, scattered across the globe, are linked and coordinated to create the equivalent of a single large coherent antenna.

Interferometers very accurately measure the wavelengths of light and distances. They send out two radio signals and use wave interference (how waves interact to reinforce or destroy each other) to determine the measurement. The data provide for an extremely accurate measurement. The two telescopes in the Westford, MA and Wetzell, Germany are about 6000 km apart. Yet from the measurements we can see a one millimeter differences in that distance. This corresponds to around one part in a billion.



For geodesy and continental drift measurements, data from a distant quasar are received at each antenna and tagged with extremely accurate timing from a hydrogen maser atomic clock, accurate to 1 second every million years! Since each antenna is a different distance from the radio source, the delays that result from the extra distance it takes for the radio signal to reach one antenna must be added artificially to the signals received at each of the other telescope's antenna. This requires a correlator to manage the data. The tape playback is synchronized using the recorded signals from the atomic clocks as time references, as shown in the picture. The approximate delay required can be found in the interference fringes. The distance can then be calculated from the geometry, which is a straightforward triangulation.

The resolution achievable using interferometry is proportional to the distance between the antennas furthest apart in the array. VLBI is most well-known in astrometry for imaging distant cosmic radio sources. However, since the VLBI technique measures the time differences between the arrivals of radio waves at separate antennas, it is used in geodesy in reverse to measure tectonic plate movement within within millimeters. Using VLBI in this manner requires large numbers of time difference measurements from distant sources (such as quasars) to be observed with a global network of antennas over a period of time.

